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UNDERWATER SOUNDS OF MIGRATING GRAY WHALES, 'ESCHRICHTIUS GLAUC--ETC(U)
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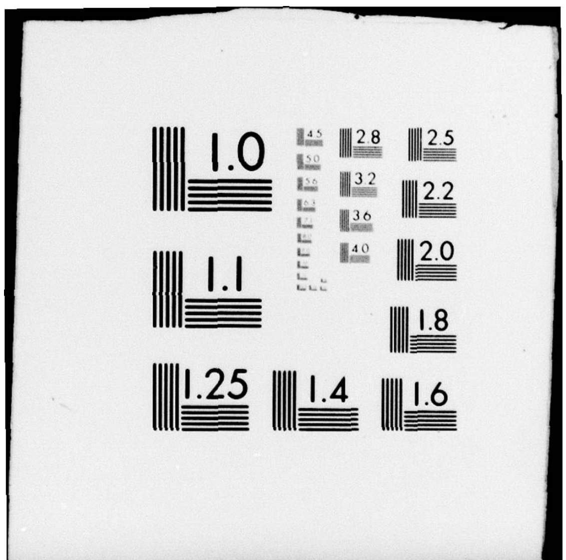

MICROCOPY RESOLUTION TEST CHART

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UNDERWATER SOUNDS OF MIGRATING GRAY WHALES, *Eschrichtius glaucus* (Cope)

10 William C. Cummings, Paul O. Thompson and Richard Cook†

Naval Undersea Warfare Center, San Diego, California 92152

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Underwater sounds from migrating gray whales were recorded from a bottom-mounted hydrophone array. Sound source locations were based upon arrival time differences and received levels. Visual tracking corroborated sound data. Moans were the most common of more than 231 whale sounds recorded in the presence of at least 218 whales. Moans lasted 1.5 sec; their source level was about 126 dB re 0.0002 dyn/cm^2 at 1 yd; and they ranged 20 - 200 Hz. Underwater blow sounds from surface exhalations were 1.25 sec long, and they ranged 15 - 175 Hz. Infrequent bubble-type signals, lasting 0.7 sec, were about 112 dB re 0.0002 dyn/cm^2 at 1 yd, ranging from 15 - 305 Hz. Knock sounds were as high as 350 Hz at sound pressure levels up to 116 dB re 0.0002 dyn/cm^2 at 1 yd. Gray whales were soniferous during the day and night. The average swimming speed of lone migrators was 5.5 knots, based on sound tracks. No characteristic behavior could be associated with sound production other than blow sounds during exhalations.

THE PURPOSE OF THIS REPORT IS TO DESCRIBE UNDERWATER SOUNDS OF GRAY WHALES as they migrated southward and to explain how these sounds could have been overlooked by previous investigators. Each fall of the year, 3,000 - 6,000[3,4] of these splendid animals leave the Arctic Ocean and

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the Bering Sea to mate or calve in the lagoons of the Baja Peninsula and the Mexican mainland. Another population migrates to Korean waters for the same reasons. Cetacean sounds often constitute a significant part of the marine sonic environment; however, there are few reports of underwater sounds from gray whales despite numerous recordings.

Eberhardt and Evans[5] reported grunts amd rumbles from gray whales in Mexico as being typically 40 - 700 Hz over a duration of 0.1 sec. Painter[6] described grunting sounds, 0.1 - 0.25 sec in duration, from sources in Mexico tentatively identified as gray whales. Each grunt consisted of 4 - 9 pulses. Walker[7] recorded a variety of sounds while observing feeding gray whales in the Bering Sea. Asa-Dorian[8] noted trains of echo-ranging clicks from a gray whale off San Diego. The clicks ranged in frequency from 0.5 to over 3 kHz. More recently, Asa-Dorian and Perkins[9] reported echolocation-like pulses (400 - 1400 Hz) and variable whistles (700 - 2200 Hz) from gray whales off San Diego and in Mexico. We recently obtained a recording from Dr. Thomas E. Poulter, Stanford Research Institute, with excepts from "12,000 feet of almost continuous animal signals," most of which he believed were from gray whales. The recording, obtained in Mexico, contained "rasps", "bongs", and "echolocation clicks" in frequencies up to 12 kHz.

Among the numerous investigators unable to relate recorded sounds to gray whales were Rasmussen and Head,[10] who monitored a total of about 200 gray whales over a period of 76 days. These authors were well equipped, having recorded under a variety of physical and behavioral conditions. They concluded that "No subsurface sounds, undeniably attributable to the gray whale, were detected."[10] They also cited a previous expedition by Hubbs and Snodgrass wherein no sounds were identified with gray whales. R. R. Mendick, K. M. Burton, of this laboratory, and the second author of this report recorded in the presence of migrating and breeding gray whales, but they were unable to attribute any signals to the whales.

Our recordings were made aboard the USS SALUDA which was moored for 13 days and nights off San Diego (January, 1966 and 1967). A bottom-mounted, calibrated hydrophone and preamplifier was positioned on each side of the ship with a separation of 525 ft between hydrophones. Two stations were used, one off Pt. Loma at a depth of 105 ft, and another off Pt. La Jolla at a depth of 65 ft. Waterborne signals were recorded on magnetic tape, one hydrophone per track. Bathythermographs indicated no temperature strata. The overall system response was essentially flat from 0.02 to 8 kHz. The two barium titanate hydrophones were built at the Naval Undersea Warfare Center, San Diego Division. Calibrations at sea were from metered 100- and 1000- Hz tones. Sound locations and source levels were calculated from arrival time differences and received sound pressure levels by assuming an average sound velocity of 4860 ft/sec, spherical spreading, and negligible attenuation. The locations of surfacing whales were estimated by using a polaris for bearing and "seaman's eye" for distance. Nearly all whales passed offshore of the array, minimizing the 180-degree ambiguity usually inherent in a 2-hydrophone system of localization. Obvious errors in sound location were attributed to perturbations in sound paths caused by proximate boundaries of the shallow water. The mean spectrum level of 157 ambient noise measurements at 100 Hz was 37 dB re 0.0002 dyn/cm^2, with a maximum difference of 10 dB between measurements. Comments were tape recorded from observers equipped with a microphone, a binaural headset, and binoculars. Observations continued round-the-clock under conditions of quiet ship and minimum light.

Two hundred thirty-one, distinct, low frequency signals were recorded, of which 108 were located. Two hundred eighteen whales were counted, but many more are believed to have passed unnoticed at night-time. Most sound locations were correlated with the estimated position of the whales. The sounds moved southward with the whales. Such correlations were not possible when sources approached equidistance from the hydrophones. Time and level differences were too small to be resolved in these cases. A similar problem with correlation arose at night, at times when whales could not be seen or heard in air. All 107 of the daytime (0600 - 1800 hrs) signals were recorded when gray whales had been sighted; none were noted without seeing whales. The range of sounds for 108 located signals varied between 10 and 1300 yds; the mean was 464 yds.

Eighty-seven percent (202) of all utterances were described as _moans_. The principal energy of _moans_ occurred between 20 and 200 Hz in about 1.5 sec (Fig. 1, A through D). The mean source level of 75 located _moans_ was 126 dB re 0.0002 dyn/cm^2 at 1 yd (range = 85 - 159 dB, standard deviation = 13.6). Short _moans_ were noted on 6 occasions. The one illustrated (Fig. 1G) was followed by 4 _knock_ sounds. A sketch of typical moan locations correlated with visual tracks of gray whales is shown in Fig. 2. Unrelated sound locations typify cases in which only one signal was obtained from passing whales. The long track (far left of Fig. 2) represents a whale's movement for about a nautical mile during which it moaned 4 times. A series of 15 moans was recorded from a lone migratory whale in a period of about 17 min (Fig. 3). The short moan (No. 14, 870 sec after the first contact) was from a distant whale which later joined the other far south of the ship.

Surface exhalations, sometimes heard in air, produced underwater blow sounds (Fig. 1E). Underwater blow sounds were indiscreet or completely masked by noise when gray whales were more than about 100 yds from the hydrophones. Underwater blow sounds were about 1.25 sec long with principal frequencies below 100 Hz.

Bubble-type signals (Fig. 1F) were recorded 13 times, and all were identified with gray whales. They consisted of a brief, low frequency pulse averaging 0.7 sec in duration and extending as high as 305 Hz. The mean source level of 13 bubble-type signals was 112 dB re 0.0002 dyn/cm^2 at 1 yd, ranging 82 - 125 dB.

Knocks such as those following the bubble-type signal and the short moan (Fig. 1F and G) were recorded 11 times, 3 of which were in conjunction with short moans and 2 with bubble-type signals. Knocks extended as high as 350 Hz, but the frequency content between signals varied considerably. Source levels from different series were 95, 98, and 116 dB re 0.0002 dyn/cm^2 at 1 yd.

We observed none of the much higher frequency echolocation signals, bongs, rasps, or whistles reported by other investigators.

Except for blows transmitted underwater, we could not observe the whale's sonic behavior, because they produced sounds while submerged. One would not expect low frequency signals, such as we have described, to be very useful in echolocation. It is suggested that they are more likely used in communication among whales. The occurrence of moans was 0 - 15 per whale in cases of lone migrators. Based on 15 moans noted in 17 min. from a passing whale, the maximum number of moans per whale/hr could be extrapolated to 53. An estimate of the percentage of all the whales observed which were soniferous would be erroneous, because there was no way of knowing how many whales in a pod actually produced the sounds recorded. Of 32 lone migrators observed, 11, about 1/3, produced sound. This proportion is probably not indicative of sound production in gray whale pods, because the two situations imply quite different behavioral characteristics.

Gray whales were soniferous day and night. One hundred twenty-four signals were recorded from at least 61 whales between 1800 and 0600 hours, compared with 107 signals recorded from at least 157 whales between 0600 and 1800 hours. All whales seen or heard at night apparently were migrating southward. The average speed of 9 lone migrators was 5.5 knots, based on daytime and nighttime tracks as long as a nautical mile.

We conclude that migratory gray whales produce discreet, low-frequency utterances described in this report as moan, blow, bubble-type, and knock sounds. Low frequency signals such as these are characteristic of mysticete whales. Apparently these sounds were overlooked during previous investigations in approximately the same locations. The explanation apparently lies with differences in procedure. First, these sounds could easily be obscured by the low frequency acceleration, flow, and strum noises which usually result from suspending hydrophones below a ship. Secondly, gray whales may not produce these sounds if they are actively confronted or pursued by man.

The underwater bio-acoustician who works in the natural environment, by one means or another, has to resolve the problems of being confronted with innumerable animal-like signals from a seeming number of possible sources. The technique of the present study was laborious and time-consuming, but it seemed expedient considering the controversy of previous observations.[9,10,11] In many instances, relative changes in received levels and arrival times on 2 hydrophones by themselves may corroborate identification of a suspected biological source when the source is moving in view.

We are grateful to the many co-workers who helped solve instrumentation problems and to Robert S. Gales for advice and encouragement. Willis L. Frisch; Stanley C. Hinricksen, SC-STI-P1, USN; and Russell L. Ludwig, CWO(4), USN, Commander of USS SALUDA, assisted while at sea. This work was supported by the Naval Ship Systems Command, subproject SF 101 03 15, Task 8119, subproject SR 104 03 01, Task 0531, and special project NUWC Z148.

FOOTNOTES AND REFERENCES

*The name E. glaucus is used to replace E. gibbosus[1] in view of a previously overlooked argument[2] on the nomenclature of the gray whale.

+Present address, USS PERRY, FPO San Francisco 96601.

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FIGURE CAPTIONS

Fig. 1. Sonagrams of gray whale signals termed moans (A-D), blow (E), bubble-type followed by knock (F), and short moan followed by knocks (G). Analyzing filter bandwidth was 1.5 Hz.

Fig. 2. Locations of representative gray whale signals, tracks, and position of ship and hydrophones (N = north, S = south hydrophones).

Fig. 3. Sonagrams and level recordings of moans from a single migratory gray whale, except for No. 14 from another lone migrator. The first moan arrivals were received at the north hydrophone (N) until the whale was about midway between hydrophones at the time of level recording No. 5. Subsequent first arrivals were at the south hydrophone (S) as the whale continued its southward course. Moans 6 - 11 were omitted for brevity. Sonagraph analyzing filter bandwidth was 1.5 Hz, and the effective filter for level recordings was 20 - 200 Hz.

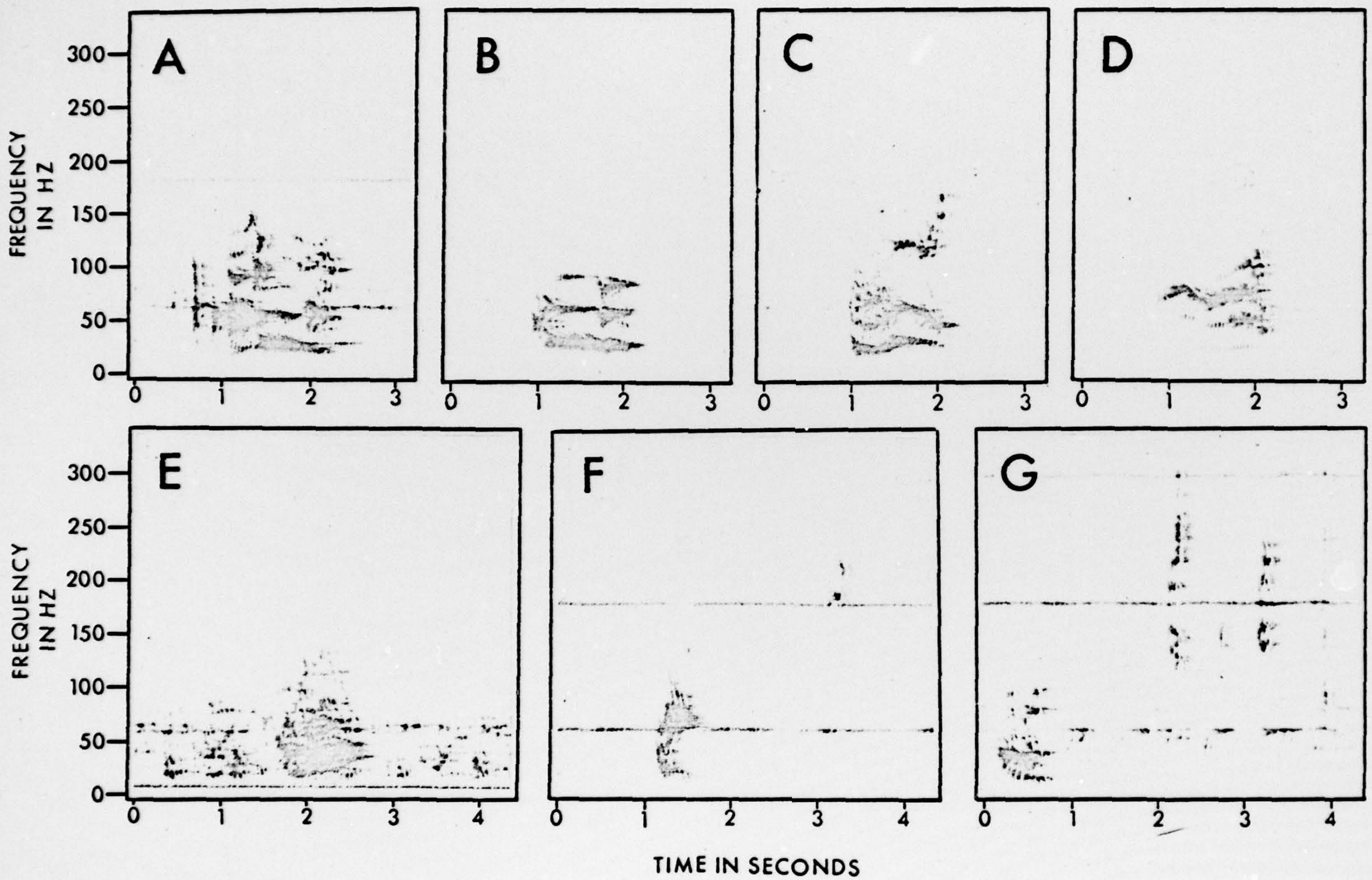

A
B
C
D
E
F
G
FREQUENCY IN HZ
300
250
200
150
100
50
0
0
1
2
3
4
TIME IN SECONDS

Fig. 1

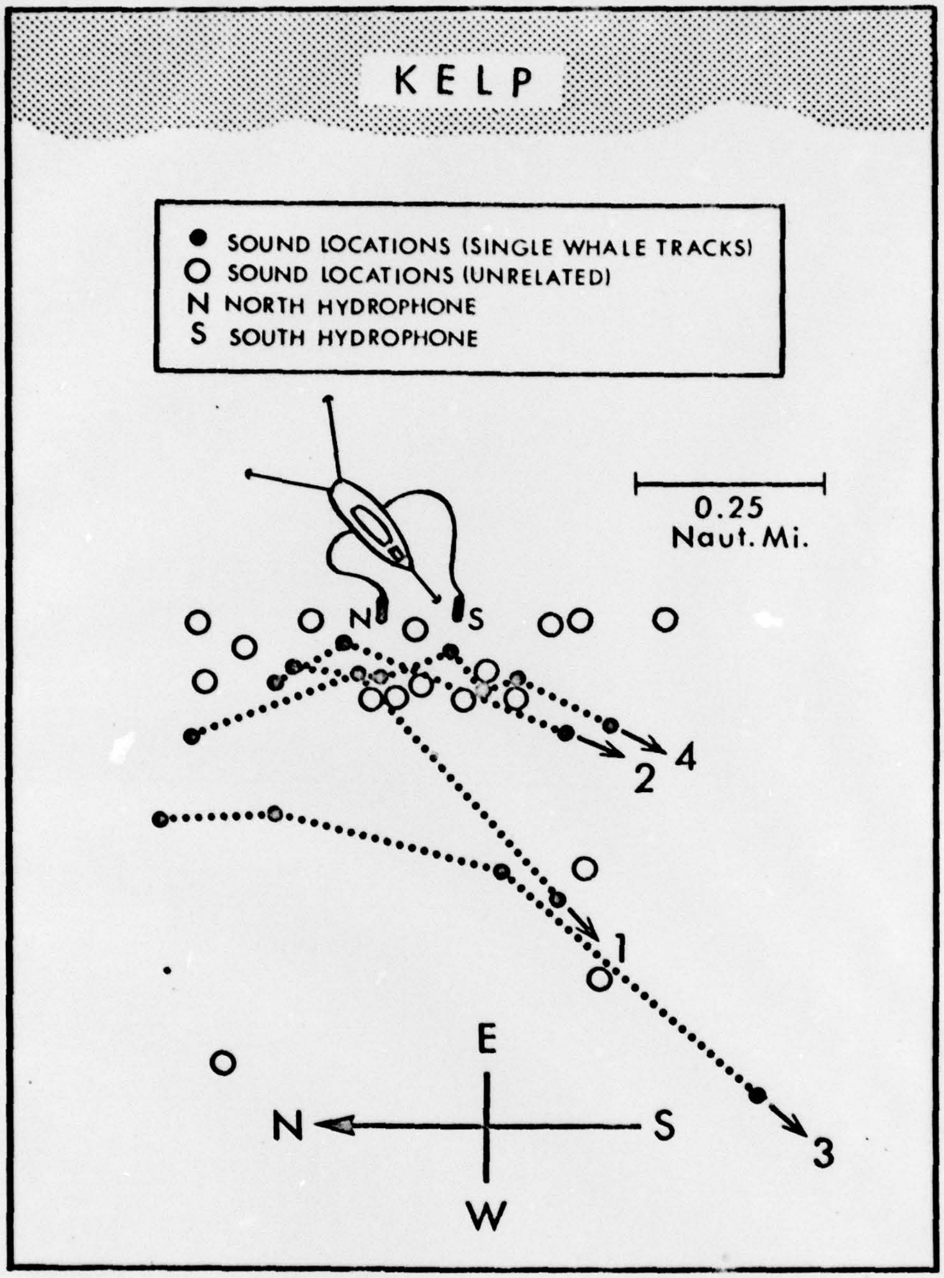
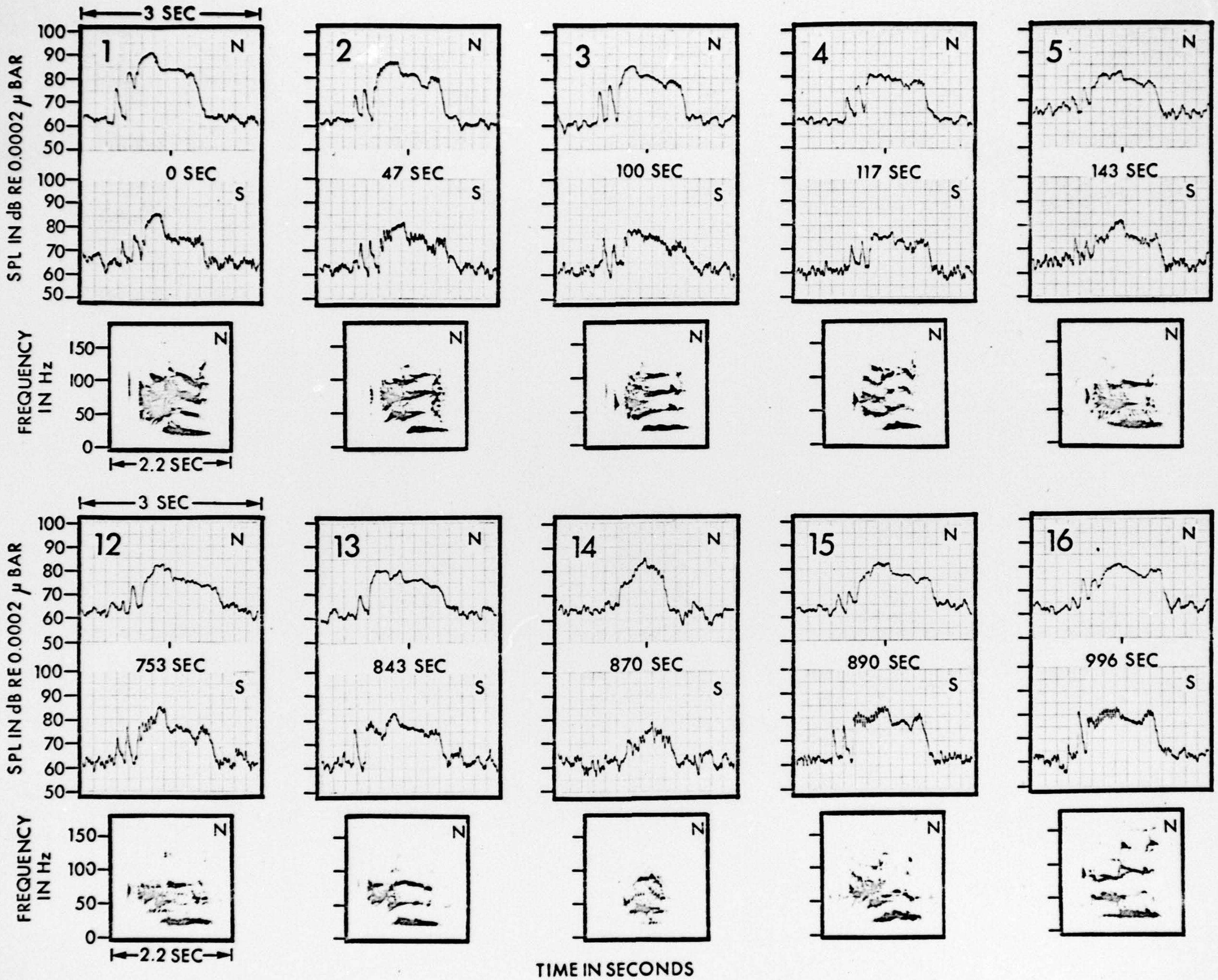

KELP
SOUND LOCATIONS (SINGLE WHALE TRACKS)
SOUND LOCATIONS (UNRELATED)
N NORTH HYDROPHONE
S SOUTH HYDROPHONE
0.25
Naut. Mi.
N
S
4
2
1
3
E
N
S
W

Fig. 2



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SPL IN dB RE 0.0002 μ BAR
FREQUENCY IN Hz
2.2 SEC
0 SEC
47 SEC
100 SEC
117 SEC
143 SEC
753 SEC
843 SEC
870 SEC
890 SEC
996 SEC
N
S
TIME IN SECONDS

Fig. 3